Appl. No. 10/053,859
Amendment dated October 28, 2004
Reply to Office Action of July 28, 2004

Amendments to Claims:

This listing of claims will replace all prior versions, and listings, of claims in the application:

Listing of Claims:

1. (currently amended) A cooling system for a heat emitting device, the cooling system operating using a fluid having a liquid phase, the cooling system comprising:

a substrate including at least a portion of a microchannel disposed therein, the substrate adapted to physically connect to the heat emitting device, thereby providing for the transfer of thermal energy from the heat emitting device to the substrate, and the further transfer of thermal energy from the substrate to the fluid disposed within the microchannel, the microchannel configured to provide flow of the fluid therethrough;

a heat exchanger configured to provide flow of the fluid therethrough and the transfer of thermal energy out of the fluid;

~~an~~ a high flow rate electroosmotic pump, the electroosmotic pump creating the flow of the fluid; and

wherein the substrate, the heat exchanger, and the electroosmotic pump are configured to operate together to create a closed loop fluid flow.

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2. (currently amended) The cooling system according to claim 1 wherein the high flow rate electroosmotic pump is disposed between the heat exchanger and the substrate such that the fluid is pumped into the microchannel of the substrate from the electroosmotic pump.

3. (currently amended) The cooling system according to claim 1 wherein the high flow rate electroosmotic pump is disposed between the heat exchanger and the substrate such that the fluid is pumped into the heat exchanger from the electroosmotic pump.

4. (original) The cooling system according to claim 1 wherein the microchannel includes a plurality of parallel subchannels, each of the parallel subchannels sharing a common inlet portion and a common outlet portion.

5. (original) The cooling system according to claim 4 further including a temperature sensor disposed in proximity to the plurality of parallel subchannels.

6. (original) The cooling system according to claim 5 further including a temperature control circuit that receives as inputs signals from the temperature sensor.

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7. (original) The cooling system according to claim 1 wherein the substrate is comprised of first and second layers, and wherein at least a portion of the microchannel is formed within both the first and second layers.

8. (original) The cooling system according to claim 1 wherein the substrate is comprised of a first layer and a second layer, the first layer being physically connected to the heat emitting device, and wherein at least a portion of the microchannel is formed within only the first layer.

9. (original) The cooling system according to claim 1 wherein heat emitting device is comprised of a plurality of integrated circuits and the substrate is disposed between the plurality of integrated circuits.

10. (original) The cooling system according to claim 9 wherein there is included at least three integrated circuits in the plurality of integrated circuits, and a second substrate is also disposed between the plurality of integrated circuits, such that each integrated circuit contains at least one surface to which one of the first and second substrates is physically connected.

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11. (original) The cooling system according to claim 1 wherein the electroosmotic pump is comprised of a plurality of layers.

12. (original) The cooling system according to claim 1 wherein the substrate further includes a plurality of vertical electrical interconnects.

13. (original) The cooling system according to claim 12 wherein the microchannel further includes vertical and horizontal fluid channels.

14. (original) The cooling system according to claim 12 wherein the plurality of vertical interconnects provide a portion of an electrical connection that electrically connects a plurality of temperature sensors to a temperature control circuit.

15. (original) The cooling system according to claim 1 wherein the substrate includes an opening through which another interaction is capable of impinging upon a portion of the heat emitting device.

16. (original) The cooling system according to claim 15 wherein the another interaction is light.

17. (original) The cooling system according to claim 15 wherein the another interaction is an electrical interaction.

18. (original) The cooling system according to claim 17 wherein the another electrical interaction is an electrical connection to a surface of the device to which the substrate is physically connected, and which electrical connection does not pass through any portion of the substrate.

19. (original) The cooling system according to claim 15 wherein the another interaction is one of pressure, sound, chemical, mechanical force, and an electromagnetic field.

20. (original) The cooling system according to claim 15 wherein the opening is a vertical column having enclosed sidewalls.

21. (original) The cooling system according to claim 15 wherein the opening is created by a surface area of the substrate that contacts a corresponding surface area of the device being smaller than the corresponding surface area of the device.

22. (original) The cooling system according to claim 1 wherein a portion of the microchannel includes:

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an upper chamber;

a lower chamber; and

a plurality of subchannels disposed between the upper chamber and the lower chamber.

23. (original) The cooling system according to claim 1 further including a pressure sensor.

24. (original) The cooling system according to claim 23 wherein the pressure sensor is disposed within the substrate.

25. (original) The cooling system according to claim 23 wherein the pressure sensor is disposed in a fluid path between the substrate and the heat exchanger.

26. (currently amended) The cooling system according to claim 25 further including another pressure sensor disposed in the fluid path between the <u>high flow rate</u> electroosmotic pump and the substrate.

27. (original) The cooling system according to claim 26 further including a temperature sensor disposed within the substrate.

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28. (original) The cooling system according to claim 27 further including a temperature control circuit that receives as inputs signals from the pressure sensor, the another pressure sensor and the temperature sensor.

29. (currently amended) The cooling system according to claim 28 wherein the temperature control circuit uses the signals from the pressure sensor, the another pressure sensor and the temperature sensor to control the <u>high flow rate</u> electroosmotic pump.

30. (original) The cooling system according to claim 1 further including a temperature sensor disposed within the substrate.

31. (original) The cooling system according to claim 30 further including a temperature control circuit that receives as inputs signals from the temperature sensor.

32. (original) The cooling system according to claim 1 further including a temperature sensor disposed in the loop at a location other than within the substrate.

33. (original) The cooling system according to claim 1 wherein the microchannel includes a portion containing a partial blocking structure to increase surface area contacting the fluid.

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34. (original) The cooling system according to claim 33 wherein the partial blocking structure is comprised of a roughened portion of a microchannel wall.

35. (original) The cooling system according to claim 33 wherein the partial blocking structure is disposed within the microchannel.

36. (currently amended) A thermal transfer apparatus connected to a semiconductor heat emitting device, the thermal transfer apparatus operating using a fluid having a liquid phase comprising:

a substrate adapted to physically connect to the semiconductor heat emitting device;

first and second microchannel fluid inlets disposed in the substrate;

first and second microchannel fluid outlets disposed in the substrate; and

first and second microchannels connected between the respective first and second fluid inlets and the first and second fluid outlets, the first and second microchannels thereby providing independent fluid flow paths <u>wherein each of the independent fluid flow paths are arranged to provide a different cooling capability to each region of the substrate in response to a requirement for cooling each region of the heat emitting device</u>.

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37. (currently amended) The apparatus according to claim 36, further including:

a heat exchanger configured to provide flow of the fluid therethrough and the transfer of thermal energy from the heat exchanger;

~~an~~ a high flow rate electroosmotic pump, the electroosmotic pump creating the flow of the fluid ; and

at least one fluid connector configured so that the substrate, the heat exchanger and the electroosmotic pump operate together using one of an open-loop and a closed loop fluid flow.

38. (currently amended) The apparatus according to claim 37 further including a ~~second~~ a high flow rate electroosmotic pump, such that the first electroosmotic pump pumps the fluid through the first microchannel and the second electroosmotic pump pumps the fluid through the second microchannel.

39. (original) The apparatus according to claim 37 further including first and second temperature sensors respectively located in proximity to the first and second microchannels, such that the first temperature sensor detects thermal energy generated by the heat emitting device in proximity to the first temperature sensor and the second

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temperature sensor detects thermal energy generated by the heat emitting device in proximity to the second temperature sensor.

40. (original) The apparatus according to claim 39 further including a third temperature sensor.

41. (original) The apparatus according to claim 40 wherein the third temperature sensor is disposed in a location that it detects thermal energy generated by the heat emitting device in proximity to the first and second temperature sensors.

42. (original) The apparatus according to claim 40 wherein the third temperature sensor is disposed between the first and second microchannels.

43. (original) The apparatus according to claim 40 wherein the third temperature sensor is disposed such that the first and second microchannels are disposed between the heat emitting device and the third temperature sensor.

44. (currently amended) The apparatus according to claim 39 further including a control circuit electrically connected to the first and second temperature sensors, the control

circuit inputting signals from the first and second temperature sensors and providing a control signal for controlling the high flow rate electroosmotic pump.

45. (currently amended) The apparatus according to claim 44 further including a second high flow rate electroosmotic pump, such that the first electroosmotic pump pumps the fluid through the first microchannel and the second electroosmotic pump pumps the fluid through the second microchannel and wherein the control circuit controls the first and second electroosmotic pumps, the control circuit being capable of independently controlling the pumping of fluid through each of the first and second electroosmotic pumps.

46. (original) The apparatus according to claim 37 further including:

first and second temperature sensors disposed within the substrate, such that the first temperature sensor detects thermal energy generated by the heat emitting device in proximity to the first temperature sensor and the second temperature sensor detects thermal energy generated by the heat emitting device in proximity to the second temperature sensor; and

a control circuit electrically connected to the first and second temperature sensors, the control circuit inputting signals from the first and second temperature

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sensors and providing a control signal for controlling the high flow rate electroosmotic pump.

47. (original) The apparatus according to claim 46 wherein the control circuit operates to sense a predetermined condition.

48. (currently amended) The apparatus according to claim 47 wherein upon sensing the condition, the control circuit causes more fluid to be pumped through the high flow rate electroosmotic pump per unit time for a period of time.

49. (original) The apparatus according to claim 47 wherein upon sensing the condition, the control circuit causes a reversal of the fluid flow for a period of time.

50. (currently amended) The apparatus according to claim 47 wherein the control circuit detects a change in temperature over a period of time and correspondingly adjusts the fluid flow within the high flow rate electroosmotic pump to compensate for the change in temperature.

51. (original) The apparatus according to claim 36 further including first and second temperature sensors respectively located in proximity to the first and second

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microchannels, such that the first temperature sensor detects thermal energy generated by the heat emitting device in proximity to the first temperature sensor and the second temperature sensor detects thermal energy generated by the heat emitting device in proximity to the second temperature sensor.

52. (original) The apparatus according to claim 51 further including a third temperature sensor.

53. (original) The apparatus according to claim 52 wherein the third temperature sensor is disposed in a location that it detects thermal energy generated by the heat emitting device in proximity to the first and second temperature sensors.

54. (original) The apparatus according to claim 52 wherein the third temperature sensor is disposed between the first and second microchannels.

55. (original) The apparatus according to claim 52 wherein the third temperature sensor is disposed such that the first and second microchannels are disposed between the heat emitting device and the third temperature sensor.

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56. (original) The apparatus according to claim 51 further including a control circuit electrically connected to the first and second temperature sensors, the control circuit inputting signals from the first and second temperature sensors and located within substrate.

57. (original) The apparatus according to claim 36, wherein the first and second microchannels each contain first and second microchannel portions that are disposed parallel and adjacent to one another such that fluid flow in the first microchannel occurs in a direction opposite the fluid flow in the second microchannel.

58. (original) The apparatus according to claim 36 wherein the first microchannel is at least partially disposed over a high thermal energy location of the heat emitting device and the second microchannel is disposed over another portion of the heat emitting device different from the high thermal energy location.

59. (original) The cooling system according to claim 36 wherein the substrate further includes a plurality of vertical electrical interconnects.

60. (original) The cooling system according to claim 59 wherein the plurality of vertical interconnects provide a portion of an electrical connection that electrically connects a plurality of temperature sensors to a temperature control circuit.

61. (original) The cooling system according to claim 36 wherein the substrate includes an opening through which another interaction is capable of impinging upon a portion of the heat emitting device.

62. (original) The cooling system according to claim 61 wherein the another interaction is light.

63. (original) The cooling system according to claim 61 wherein the another interaction is an electrical interaction.

64. (original) The cooling system according to claim 63 wherein the another electrical interaction is an electrical connection to a surface of the device to which the substrate is physically connected, and which electrical connection does not pass through any portion of the substrate.

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65. (original) The cooling system according to claim 61 wherein the another interaction is onc of pressure, sound, chemical, mechanical force, and an electromagnetic field.

66. (original) The cooling system according to claim 61 wherein the opening is a vertical column having enclosed sidewalls.

67. (original) The cooling system according to claim 36 wherein a portion of at least one of the first and second microchannels includes:

an upper chamber;

a lower chamber; and

a plurality of subchannels disposed between the upper chamber and the lower chamber.

68. (original) A thermal transfer apparatus that operates using a fluid having a liquid phase comprising:

a semiconductor heat emitting device, the semiconductor heat emitting device including a thermal control circuit:

a substrate adapted to physically connect to the semiconductor heat emitting device;

first and second microchannel fluid inlets disposed in either the substrate or the semiconductor heat emitting device;

first and second microchannel fluid outlets disposed in either the substrate or the semiconductor heat emitting device;

first and second microchannels disposed in either the substrate or the semiconductor heat emitting device connected between the respective first and second microchannel fluid inlets and the first and second fluid microchannel outlets, the first and second microchannels thereby providing independent fluid flow paths; and

first and second temperature sensors disposed within the substrate and electrically connected to the thermal control circuit so that the signals from the first and second temperature sensors are input to the control circuit.

69 - 84. (canceled)

85. (original) A method of placing a microchannel in a substrate so that the microchannel can transfer fluid having a liquid phase therethrough and dissipate thermal energy in a particular integrated circuit chip comprising the steps of:

selecting the particular integrated circuit chip:

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using a computer, predicting locations and cross sectional shapes of the microchannel in the substrate that will sufficiently dissipate thermal energy with the fluid flowing therethrough, the step of predicting locations and cross sectional shapes of the microchannel including the step of iteratively computing fluid and solid temperature and pressure distributions for iteratively determined potential locations and potential cross sectional shapes of the microchannel in the substrate; and

creating the microchannel at the predicted microchannel locations with the predicted cross sectional shapes in the substrate.

86. (original) The method according to claim 85 wherein the step of iteratively computing fluid and solid temperature distributions uses empirical convection and fluid drag coefficients.

87. (original) The method according to claim 85 wherein the step of iteratively computing fluid and solid temperature distributions uses non-empirical solutions to energy and momentum equations in the microchannel.

88. (original) The method according to claim 85 wherein the step of iteratively computing fluid and solid temperature distributions uses empirical correlations for temperature and

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pressure that are dependent upon liquid and vapor properties of the fluid in the microchannel.

89. (original) The method according to claim 85 wherein the step of predicting considers:

conduction in walls at potential locations and for potential cross sectional shapes of the microchannel; and

convection in the fluid;

when computing the temperature and pressure distribution.

90. (original) An apparatus for use with a cooling system operating using a fluid having a liquid phase, the apparatus comprising:

a heat emitting device, the heat emitting device including a heat emitting element; and

a substrate physically connected to the heat emitting device, with the heat emitting device and the substrate each containing at least a portion of a microchannel, thereby providing for the transfer of thermal energy from the heat emitting device to the substrate, and the further transfer of thermal energy to the fluid disposed within the microchannel, the microchannel configured to provide flow of the fluid therethrough.

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91. (currently amended) The apparatus according to claim 90, further including:

a heat exchanger configured to provide flow of the fluid therethrough and the transfer of thermal energy out of the fluid;

~~an~~ a high flow rate electroosmotic pump, the electroosmotic pump creating the flow of the fluid; and

wherein the substrate, the heat exchanger, and the electroosmotic pump are configured to operate together to create one of a closed loop fluid flow and an open loop fluid flow.

92. (original) The cooling system according to claim 90 wherein the substrate further includes a plurality of vertical electrical interconnects.

93. (original) The cooling system according to claim 92 wherein the plurality of vertical interconnects provide a portion of an electrical connection that electrically connects a plurality of temperature sensors to a temperature control circuit.

94. (original) The apparatus according to claim 93 wherein the temperature control circuit is part of the heat emitting device.

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95. (original) The cooling system according to claim 90 wherein the substrate includes an opening through which another interaction is capable of impinging upon a portion of the heat emitting device.

96. (original) The cooling system according to claim 95 wherein the another interaction is light.

97. (original) The cooling system according to claim 95 wherein the another interaction is an electrical interaction.

98. (original) The cooling system according to claim 97 wherein the another electrical interaction is an electrical connection to a surface of the device to which the substrate is physically connected, and which electrical connection does not pass through any portion of the substrate.

99. (original) The cooling system according to claim 95 wherein the another interaction is one of pressure, sound, chemical, mechanical force, and an electromagnetic field.

100. (original) The cooling system according to claim 95 wherein the opening is a vertical column having enclosed sidewalls.

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101. (original) The cooling system according to claim 90 wherein a portion of the microchannel includes:

an upper chamber;

a lower chamber; and

a plurality of subchannels disposed between the upper chamber and the lower chamber.

102 – 110. (canceled)

111. (currently amended) A cooling system for a heat emitting device, the cooling system operating using a fluid having a liquid phase, the cooling system comprising:

a substrate including at least a portion of a microchannel disposed therein, the substrate adapted to physically connect to the heat emitting device, thereby providing for the transfer of thermal energy from the heat emitting device to the substrate, and the further transfer of thermal energy from the substrate to the fluid disposed within the microchannel, the microchannel configured to provide flow of the fluid therethrough;

a heat exchanger configured to provide flow of the fluid therethrough and the transfer of thermal energy from the heat exchanger;

~~an~~ a high flow rate electroosmotic pump, the electroosmotic pump creating the flow of the fluid; and

wherein the substrate, the heat exchanger, and the electroosmotic pump are configured to operate together using an open loop fluid flow.

112. (currently amended) A method ~~of~~ for providing for heat transfer away from a heat emitting device comprising:

using ~~an~~ a high flow rate electroosmotic pump to create a flow of a fluid having a liquid phase;

directing the fluid flow to pass through a microchannel in a substrate with the substrate physically connected to the heat emitting device to thereby create a heated fluid; and

further directing the heated fluid to pass through a heat exchanger to thereby create a cooled fluid; and

causing the steps of using, directing and further directing to operate to create a closed loop fluid flow.

113. (currently amended) The method according to claim 112 wherein the step of directing directs the flow of fluid from the high flow rate electroosmotic pump into the microchannel of the substrate.

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114. (currently amended) The method according to claim 112 wherein the step of directing directs the flow of fluid from the <u>high flow rate</u> electroosmotic pump into the heat exchanger.